APPENDIX 5

TESTS OF LIQUID HELIUM RELEASES AT BNL, FNAL AND CEBAF

BROOKHAVEN NATIONAL LABORATORY
Safety and Environmental Protection Division

MEMORANDUM

DATE: April 2, 1996

TO: S. Musolino

FROM: R. Selvey

SUBJECT: **Helium Gas Release Tests in RHIC 1012 Q5 Tunnel**

S. Kane, R. Wilson, and I conducted testing to determine the impact on oxygen levels (Oxygen Deficiency Hazard, ODH) that could result from a RHIC cryogenic component leak of gaseous helium into the ambient air in the tunnel. Tests with liquid spills and higher flow rates of gaseous helium have been reported in other studies. The tests we made were to determine oxygen displacement in relatively small leaks of gaseous helium. The ambient oxygen levels were measured over several days inside the tunnel while various tests were performed. Measurements were made with three Bacharach Sentinel 44 multi-gas detectors that include a galvanic, electrochemical sensor for measurement of oxygen. These meters report oxygen level to the nearest 0.1% and were calibrated (set to read 20.9%) in the outdoor air on each day of testing. On most tests, readings were made in duplicate or triplicate with good agreement between the meters in precision and accuracy.

In gaseous leak tests at the tunnel 12 o'clock location (Q5), the oxygen level never deviated from 20.9% at the breathing zone height (5-6 feet from the floor) and at the ceiling. In these tests, helium was released from compressed gas cylinders three inches above floor level into the tunnel at flow rates of 4, 40, 120 and 200 cfh (0.07, 0.7, 2.1 and 3.3 cfm). Oxygen level measurements were taken 1 inch from the source, 12 to 20 inches from the source, at breathing zone height directly above the source, and at ceiling height above the source and 15 feet to either side of the release. Measurement taken directly in-line of the flow of gas recorded significantly reduced oxygen levels, often down to the very low % levels (5% or less). Measurements more than 3 to 4 inches to either side of the center line of the gas stream did not detect reduced oxygen levels. Measurements taken 3-4 inches above the gas stream showed a 1 to 2 % oxygen reduction. No oxygen level reduction was detected when the probe was more than 1 foot away from the gas stream. The survey results of this test are presented in Table 1.

A second series of tests to determine stratification and the dispersal rate from an unvented alcove were conducted. When approximately 300 cubic feet of helium were released (rate of 900 cfh) at floor height, only a very slight reduction (less than 1%) in the oxygen level was detected at the ceiling of the 1000 cubic foot alcove (Q5). In another test, approximately six hundred (600) cubic feet of gaseous helium were released at ceiling height at a rate of 200 cfh into the 140 square foot alcove (Q5). If the assumption that helium does not mix, rises, stays at the ceiling, and "flows like a river" is true, then in theory, a two foot deep "blanket" of helium should have been created at the ceiling with a well-defined boundary. Instead, a minimum level of 5% oxygen was measured up to six inches from the ceiling at the end of the delivery of all the gas. A gradient of increasing oxygen concentration was detected, increasing to 12.5% five feet below the ceiling.

The oxygen level change with distance from the ceiling was gradual, instead of characterized by sharp stratification. The concentration in the alcove was monitored over time to determine dispersion and mixing with ambient air. At 20 hours, the level at the ceiling had increased to 17.8% and the blended to 20.6% at 5 feet below the ceiling. By 26 hours, all points from ceiling to the face of the alcove were at 20.9% (atmospheric) oxygen.

The air movement in the tunnel during the tests was measured at less than 50 fpm with an Alnor Thermoanemometer. Irritant smoke tubes were used to detect the direction and velocity of air currents in the tunnel visually. Some air movement and dilution occurred from the occasional opening of tunnel entrances hundreds of feet away from the test site. All entrances in the immediate vicinity of the test were closed during the days of testing. No exhaust ventilation was in operation. The temperature in the tunnel was in 15-20 degree Celsius range.

The monitoring data suggests the following:

a. Oxygen sensors at the ceiling will detect the greatest reduction in oxygen levels, but the concentration at other heights may be the same or only slightly higher in oxygen content. The assumption that detectors at the ceiling set to 18% will warn of oxygen levels at 19.5% in the breathing zone height may not hold true for gaseous releases.
b. A high degree of mixing of the gaseous helium with the ambient air appears to occur at the height of release and above.
c. The "flows like a river of pure helium" theory does not seem valid for gaseous releases.

Based on these results and a review of the other tests, I believe discussions need to be held between RHIC and SEP to discuss the ODH monitoring strategy for the RHIC tunnel, including:

a. Monitoring when tunnel is occupied and not occupied,
b. Advantages/disadvantages of portable, personnel monitors -v.s. fixed, area monitoring,
c. Using multiple, fixed detectors in the tunnel -v.s. continuous pumping of tunnel air to detectors outside radiation areas (detectors could then be checked with the oxygen level in air outside the tunnel at will), and
e. Setting the alarm point of sensors at 18% -v.s. 19.5%.

cc: G. Adams
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IH6920.95

Table 1: Release of Gaseous Helium in RHIC Tunnel

Helium Flow Rate (cfh)	Run Time (min)	Oxygen Level % O_2 at Sensor Location			
		1 inch from source	20 inches from source	Breathing Zone	Ceiling
0	0	21.0	21.0	21.0	21.0
4	Start	<15	-	-	21.0
	5	-	-	-	21.0
	15	<15	-	-	21.3
	20	-	21.0	-	21.3
	30	-	21.0	-	21.3
	40	-	21.0	-	21.4
	45	-	21.0	-	21.4
	50	-	21.0	-	21.4
	60	-	21.0	-	21.4
40	Start	-	21.0	-	20.9
	5	-	21.0	-	21.0
	15	-	21.0	-	21.0
120	Start	-	21.0	-	20.9
	5	-	21.0	-	-
	10	-	-	-	21.0
	15	-	-	-	20.9
	20	-	-	-	20.8
	25	-	-	-	21.0
	30	-	-	-	21.0
200	Start	-	-	-	20.9
	5	-	-	-	20.9
	10	-	-	-	21.0
	15	-	-	-	21.0

Table 2: Helium Release into Alcove Q5

Release Rate	Release Location	Run Time (min)	O_2 at ceiling	O_2 at Breathing Zone	
Cylinder valve open, unquantified flow rate (Approx> 900 cfh)	On floor, (Cylinder on side, below alcove opening, pointing up)	0	21.1	-	
		2	20.9	-	
		5	20.8	-	
		10	20.9	21.3	
		15	20.6	-	
		20	20.9	-	
		25	21.2	21.5	
200 cfh	Release at ceiling of alcove	Time (min)	At Ceiling	6" below Ceiling	1 foot below ceiling
		0	20.9	20.9	-
		1	19.3	20.2	-
		2	18.6	19.9	
		5	18.0	19.4	
		9	17.8	18.4	20.1
		15	17.1	17.8	19.3
		20	16.6	17.2	18.2
		25	16.0	16.9	18.0
		30	15.5	16.1	18.1
		40	14.7	15.4	16.0
		50	14.3	15.1	16.3
		60	13.7	14.3	14.1
		80	12.3	12.7	14.1
		90	11.7	12.0	14.0
		180	11.0	8.4	11.8
		240	5.4	-	5.0
		1200	17.8	-	-
		1560	20.9	-	20.9

IEEE Transactions on Nuclear Science, Vol. NS-30, No. 4, August 1983

OXYGEN DEFICIENCY HAZARD INDUCED BY HELIUM RELEASE IN ACCELERATOR TUNNEL*

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Summary

Tests to investigate oxygen deficiency levels due to release of helium into the CBA tunnel are described. Results of the tests indicate that the helium stratifies and spreads quickly in the horizontal plane. This demonstrates that adequate warning of possible asphyxiation hazards can be achieved. When oxygen deficiency monitors are located at ceiling level they may be spaced at intervals of 60 m. or more and still achieve acceptable results.

Background

There have been many instances where death has resulted from asphyxiation in confined spaces such as submarines, storage tanks, etc. All cases which were found involved gases which are heavier than air. The CBA tunnel will house superconducting magnets and cryogenic piping which could upon failure release very large quantities of helium into the confines of the tunnel.

The only data found for helium releases in a similar configuration was in an unpublished Fermilab report on a simulated, large-scale liquid helium spill in their tunnel.

The study reported in this paper was instituted specifically to determine if a relatively small leak could, over a long period of time, go undetected by the Oxygen Deficiency Monitors (ODM) in the CBA tunnel and create a pocket where a potentially dangerous deficiency of oxygen could exist.

Test Site Geography

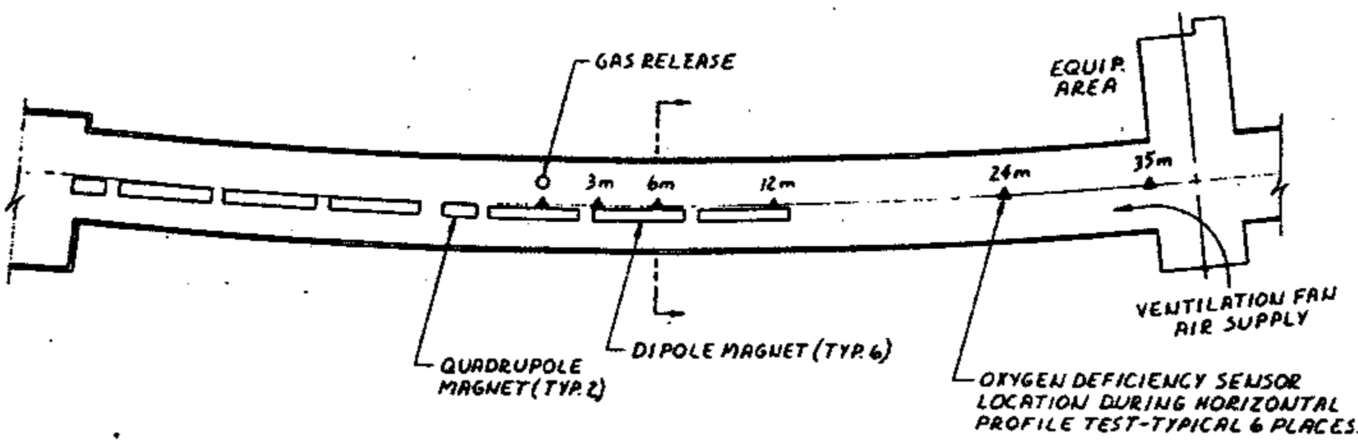
The tests were carried out at CBA Sextant V East Injection/Ejection area during initial stages of magnet installation for the "Full Cell" test program. The tunnel cross-section is shown in Figure 1 and has an area of approximately 14 sq. meters. ODM sensors were located in positions as shown in the plan view of Figure 1. The sensors were mounted at the highest point of the ceiling, approximately 3.3 meters from floor level for the horizontal flow tests and were later grouped and arranged vertically as shown in the tunnel cross-section of Figure 1 to measure floor to ceiling oxygen gradients.

A push-pull fan system provides emergency ventilation for the tunnel. The push-pull ratio is chosen so that a slight negative pressure is created in the tunnel. The air flow during operation of these fans is from right to left in Figure 1. When all fans are energized an air flow velocity of 0.6 meters per second sweeps the tunnel.

The normal ventilation system was turned off during the test period. A smoke test showed that when the fans were off tunnel air was motionless, providing optimum conditions for helium build-up from a small leak.

Apperatus Description

Oxygen Deficiency Monitors used for the tests consisted of two four-channel "Gas-Mark" continuous gas monitors purchased from "Lumidor Safety



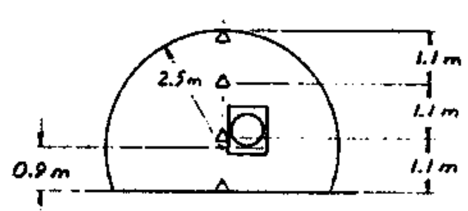


Figure 1. Plan and cross-section views of test area which is a section of the CBA tunnel. Magnets shown are those used in the Full Cell Test.

*Work performed under the auspices of the U.S. Department of Energy.

Products," Miami, Florida. Each system contained four independent oxygen sensing beads connected to a common box which housed alarm and indicator lights, an audible alarm, contacts for external control, battery backup and digital panel meter switchable to read the oxygen level at any one of the four heads and the preset alarm trip point. Oxygen sensing detectors in each head were manufactured by "Teledyne Analytical Instruments," modified to Lumidor specifications. The sensors are a galvanic electro-chemical cell generating a voltage which is linear from 0 to 25% oxygen partial pressure in nitrogen. The detectors exhibit sensitivity to only oxygen and are temperature compensated over a range of 0 to 40°C. Overall system accuracy is ±1/2%.

Throughout the tests two Gould four-channel chart recorders were used to graph the events. One chart recorder channel was connected across each head as its signal entered the alarm box. Recorder time bases were calibrated and the recorder's zero was offset to permit a total chart sensitivity of approximately 2% oxygen.

Helium gas supply came from a screw compressor which normally supplies gas to a helium refrigerator. A supply line was extended down the tunnel to the release area where flow was modulated by a manual valve. The flow rate was measured by a Hastings helium mass flow meter. Helium exited from 1.25 cm diameter copper tubing at about .5 m above floor level. The gas jet was aimed in a horizontal direction, perpendicular to the tunnel wall.

Test Results

During the series of tests helium was released into the tunnel at flow rates of 1, 5, 10 and 15 grams/second with ODM sensors located as shown in the plan view in Figure 1. A composite of the ODM graphical records at 15 g/s flow, is shown in Figure 2. Tests showed that a release rate of 15 g/s produced results that were typical of release rates of 5 and 10 g/s with respect to both the horizontal propagation velocity and the O_2 concentration in still air at steady state conditions. From this data the following conclusions can be drawn:

A. The ODM sensors have a time delay of about 5 or 6 seconds from the arrival of helium at the sensor until the sensor output begins to rise.

B. Typical rate of change is 0.02 percent oxygen per second.

C. The horizontal propagation velocity of the helium front was typically 0.3 m/s.

D. The above characteristics are acceptable for our intended use, i.e., to warn of an O_2 deficiency in a relatively short time after release of helium into the tunnel.

E. For all flow rates, including the highest (15 g/s), the O_2 level never dropped below 20% at the ceiling level where the sensors were located. (OSHA requires a minimum of 19.5% for continuous occupancy.)

F. When the emergency ventilating fans were operated while the helium release continued, they were able to clear the tunnel of helium at locations upstream (toward the air supply) from the release point, but had little effect on the readings downstream from the release point.

G. The emergency ventilation fans cleared the tunnel effectively when the helium release was stopped. The time required to clear seems to be independent of the helium release rate used.

The test sequence for the 1 g/s release rate yielded a lower propagation velocity (0.2 m/s) and a higher steady state O_2 level (20.6 %) than the tests with higher flow rates.

Following the tests with the ODM sensors spread horizontally at ceiling level, four sensors were relocated in the vertical grid shown in the tunnel cross-section of Figure 1. The grid was located 6 meters up the tunnel from the helium release point toward the air supply from the fans. The helium release rate was 15 g/s for this test. The response of the sensor (see Figure 3) at the ceiling (elev. 3.3 m.) and the sensor at elev. 2.2 m. were nearly the same until the fans were turned on. In response to the fans, the sensor at elev. 2.2 m. showed a slow increase in O_2 concentration and at about that same time some slight amounts of helium were detected by the sensors located at the floor (elev. 0) and at elev. 1.1 m. It can be assumed that the fans caused turbulence which mixed the helium and air, causing

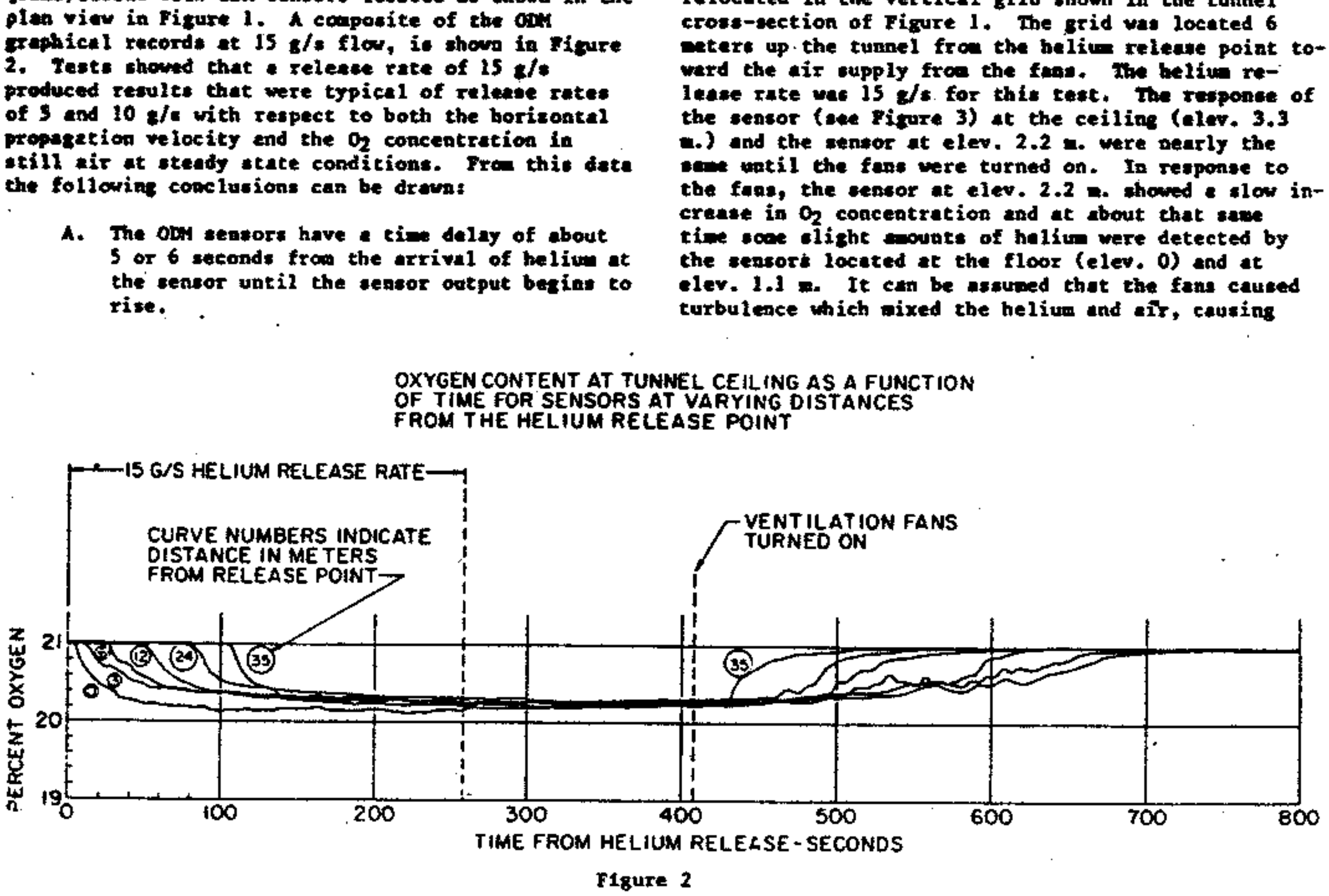


Figure 2

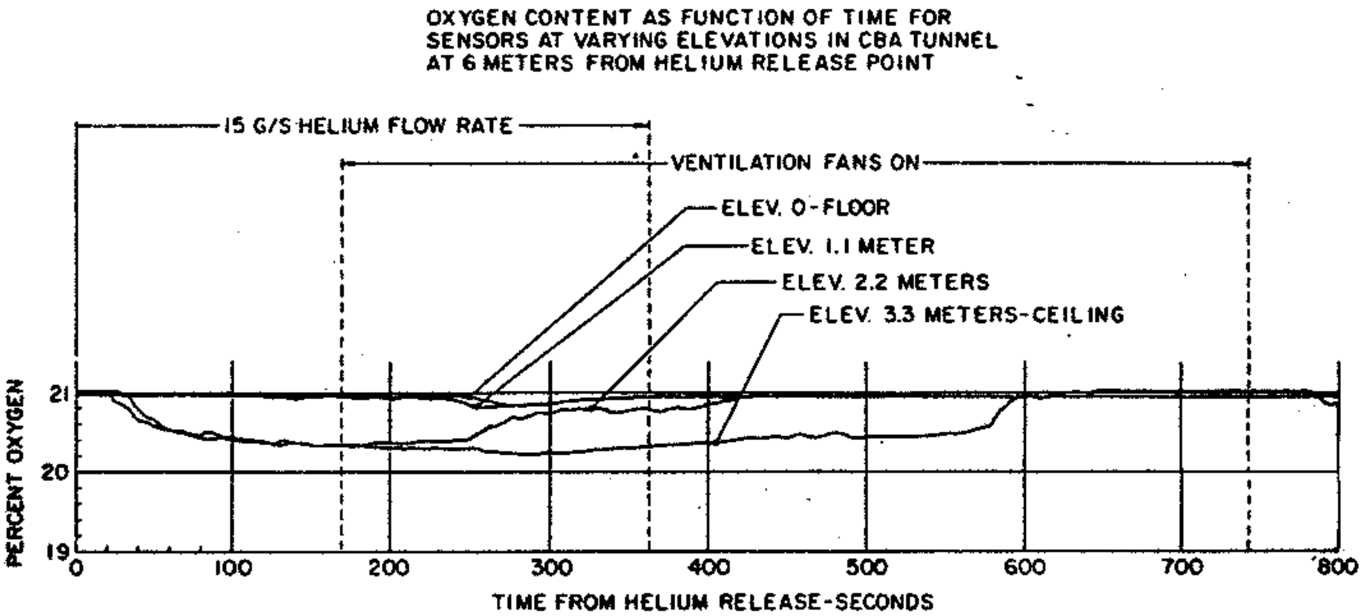


Figure 3

the O_2 concentration to rise at the 2.2 m. elevation while causing it to fall at the two lower elevations.

These test results indicate that the helium does tend to rise rather than mix evenly throughout the tunnel cross-section. This is convenient from the standpoint of detecting oxygen deficiency due to helium leakage because a detector located at the ceiling will always indicate the lowest O_2 concentration and it is unnecessary to sample at other elevations. This would not be the case if significant quantities of inert gases of higher density than air were used in the tunnel.

Fermilab

SIMULATION OF ACCIDENT INVOLVING THE RELEASE
OF LIQUID HELIUM INTO THE MAIN RING TUNNEL

Howard Casebolt and Peter J. Limon

I. PURPOSE

The purpose of the test was to show the effects of releasing large quantities of liquid helium into the Main Ring tunnel in a short period of time. The amount of liquid vented was approximately 350 liters in a fraction of a minute at the A-22 location. That amount is equal to one half of a cryoloop.

The test corresponds to a possible accident in which a cart or magnet vehicle hits a spool piece and tears off all of the relief valves on that spool piece. That sort of accident vents more helium into the tunnel than a rupture of the vacuum along with destruction of the relief valves, because when the vacuum is destroyed, the sudden heating results in high single phase pressure, which opens many other relief valves, venting most of the helium into the 8" header.

The test is a realistic simulation of the short term effects (perhaps the first few minutes) of such an accident in the final system. The long term effects which would result in the final system would be more severe, since some fraction of the transfer line from the CHL might also be emptied, venting into the tunnel.

II. SET-UP AND INSTRUMENTATION

The simulation was performed by installing three Kautzky-style valves at the A-22 spool piece, and opening them simultaneously. The single phase and two phase valves pointed down from a height of about one foot off the floor, and the nitrogen relief pointed upstream.

Figure 1 shows the location of the instrumentation in the immediate vicinity of A-22. There were four types of instruments used to measure the effects of the test.

1. Television Monitors: Three cameras were placed in the tunnel at the locations shown in Fig. 1, each about two feet off the floor. Cameras one and two were video taped, but unfortunately only the video tape of camera one was usable, due to instrument failure or operator error. In addition, there was audio at A-22. The impressions are discussed in Section III.

2. Oxygen Analyzers: Eight oxygen analyzers were placed at various places in the tunnel, and were either recorded on a chart recorder at A-2 Service Building or read out in the Main Control Room on a slow time plot. In addition to the six shown in Fig. 1, there were two more at A-35 (+1100') and A-25 (+500') located at approximately head height. Figure 2 shows the output of each of these devices. There are clearly some problems with some of the analyzers. The one at A-22 (head height) rises to a very high level after nine minutes, and then comes back to its original value. This is thought to be due to moisture condensing on the sensor which will cause a high reading. This also means that the actual oxygen level at the sensor might have decreased to a lower value than was indicated because of this same moisture effect. The analyzers at A-22 (+20' - knee height) and at A-25 (knee height) show no response. Although it is known that the analyzers themselves were in working order from a later test, it is possible that the chart recorder had some intermittent problem. In our opinion it is not likely that the analyzer at A-22 (+20') not show some

effect, either temperature or oxygen displacement. Viewing of the video tape shows that the vapor cloud appeared to be above the knee height sensor at that point, however.

3. Four temperature monitors were used as shown in Fig. 1. These were 100Ω platinum resistors, read out on a chart recorder at the A-2 Service Building. The temperature coefficient of the resistors was 0.385 Ω/°C; R = 100Ω at T = 0°C. The estimated reading uncertainty of the data is 50 mvolts, corresponding to a temperature uncertainty (relative) of ~3°C. Figure 3 shows the time response of temperature. We believe that the resistor at A-22-2 was offset by about 10°C since the quiescent temperature in the tunnel was close to 20°C, not 11°C as shown.

4. One leak detector was placed at the bottom of the stairwell at A-25, equipped with a sniffer probe that sampled the tunnel air. Set on the least sensitive scale, 100% helium atmosphere was 88 units. However, it appears that the detector was very non-linear in response at this high level, and should not be taken as an absolute measurement of the helium contamination in the air.

III. DISCUSSION OF RESULTS

A. From the TV monitors, the following conculsions can be made:

1. The helium was completely vented from the magnets in a fraction of a minute, possibly even in a few seconds, creating a swirling cloud of fog in the immediate vicinity of the relief valves, extending 10 or 20 feet upstream and downstream. There was a distinct sound of rapidly flowing liquid, but no loud noise, as there is when there is a high current quench.

2. The cloud had a high degree of internal turbulence, but did not visibly move, as a unit, either up or down the tunnel. After about one minute there was a clear stratification in density of the cloud, with the region near the floor being less dense. After about two minutes, the region near the floor began to clear. The cloud dissipated itself by flowing downstream in a shallow river at the apex of the tunnel. It should be noted that the internal tunnel circulation flows downstream at about three miles per hour. The cloud did not move as a unit but appeared to remain stationary except at the top of the tunnel. After two minutes, there was still fog being generated in the vicinity of the relief valves. It is not known whether there was any remaining cryogenic fluids escaping, or whether this was due to condensation near the cold relief valves, and spool piece. It appears from the video tapes that the nitrogen may still have been venting at this time.

B. Oxygen depletion:

1. From the oxygen analyzers, it appears that the helium gas traveled in bulk at about 200 feet/min. The lowest recorded value of oxygen was 15% at A-21 (100' upstream) and 16% at A-22 and at the top of the A-25 stairwell. Because of possible calibration problems due to moisture, it is probable that the value at A-22 at head height was considerably lower than the recorded 16%.

2. The most striking result, it if is true, is the absence of oxygep depletion at A-22 (20' downstream) at knee height. This analyzer was tested the next day and appeared to be in working condition. If that is so, it means tha staying close to the floor, and only 20' from the blowout is quite safe, as

far as oxygen is concerned. In any case, one could move at a swift pace and keep ahead of the depletion region.

3. It is interesting to observe the helium leak detector (Fig. 4). It responded roughly on the same time scale as the oxygen analyzer. Shortly after the tunnel exhaust fan was turned on at B-1 location (+11 minutes), the leak detector shows a large response. We believe that this was due to helium being pulled down from the top of the stairwell just past the detector, which was only two or three feet upstream of the bottom of the stair. Also, at +70 minutes, the leak detector shows a sharp upward response, at a level two orders of magnitude less than the initial response. It is possible that this is helium coming around the tunnel due to the natural circulation in the tunnel. A three mile per hour circulation would correspond to about 75 minutes around the tunnel. It is also possible that this is due to some more mundane event; for example, the liquid nitrogen level in the trap going to a low level. Before there was a clear indication of the downward side of the response, the leak detector began to malfunction, probably due to too high a total pressure.

C. Temperature:

1. Clearly, the most spectacular result is the low temperature in the vicinity of the spill. The temperature fell very fast to -50°C (-75°F) at four foot height, and -70°C (-95°F) at one foot height within 30 seconds. Although the temperature then increased quite quickly, it was still -10°C after five minutes. It is possible that these temperatures could cause injury, particularly to a person's lungs. At ~-45°C lung tissue begins to freeze. (Ref. NASA.)

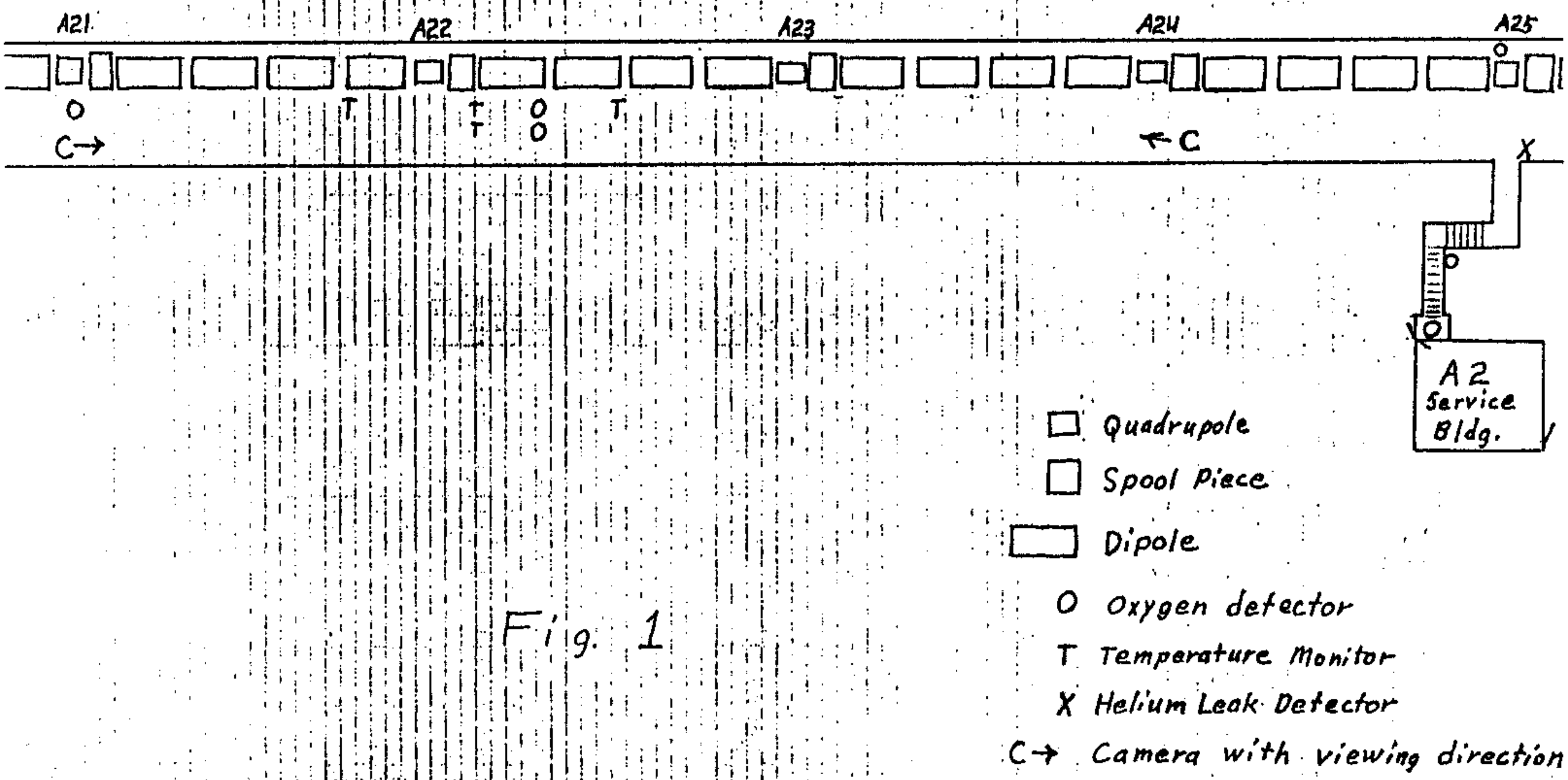
However, 20 feet upstream and 40 feet downstream, the temperature change was only about 10°C. We believe, as mentioned before, that there was a zero offset problem on the thermometer at A-22-2, but that the change in temperature is correct.

2. The large fluctuations in temperature at A-22 are probably due to turbulence in the tunnel air.

IV. CONCLUSION

Although the results of the test show that such an accident is not benign, it also shows that fast action can prevent personal injury. Clearly the first problem encountered in the region of a break of this sort is low temperature with oxygen a secondary problem. An individual who does not move away from the immediate area fast enough, could in one breath damage his lungs. The time response for this particular accident showed that an individual walking rapidly would exit from the first exit. However, accidents that occur closer to an exit would decrease this time interval. In general, the most reasonable response is to move quickly from the area, keeping low, and exit from the second exit removed from the spill area.

It should be mentioned that there was no apparent physical damage to the Saver equipment, the Main Ring, or to the Main Ring tunnel. The only damage that occurred was to an extension cord that was draped around the Kautzky valves. The outer insulation jacket shattered from the cold.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T Temperature Monitor
X Helium Leak Detector
C→ Camera with viewing direction

Fig. 1

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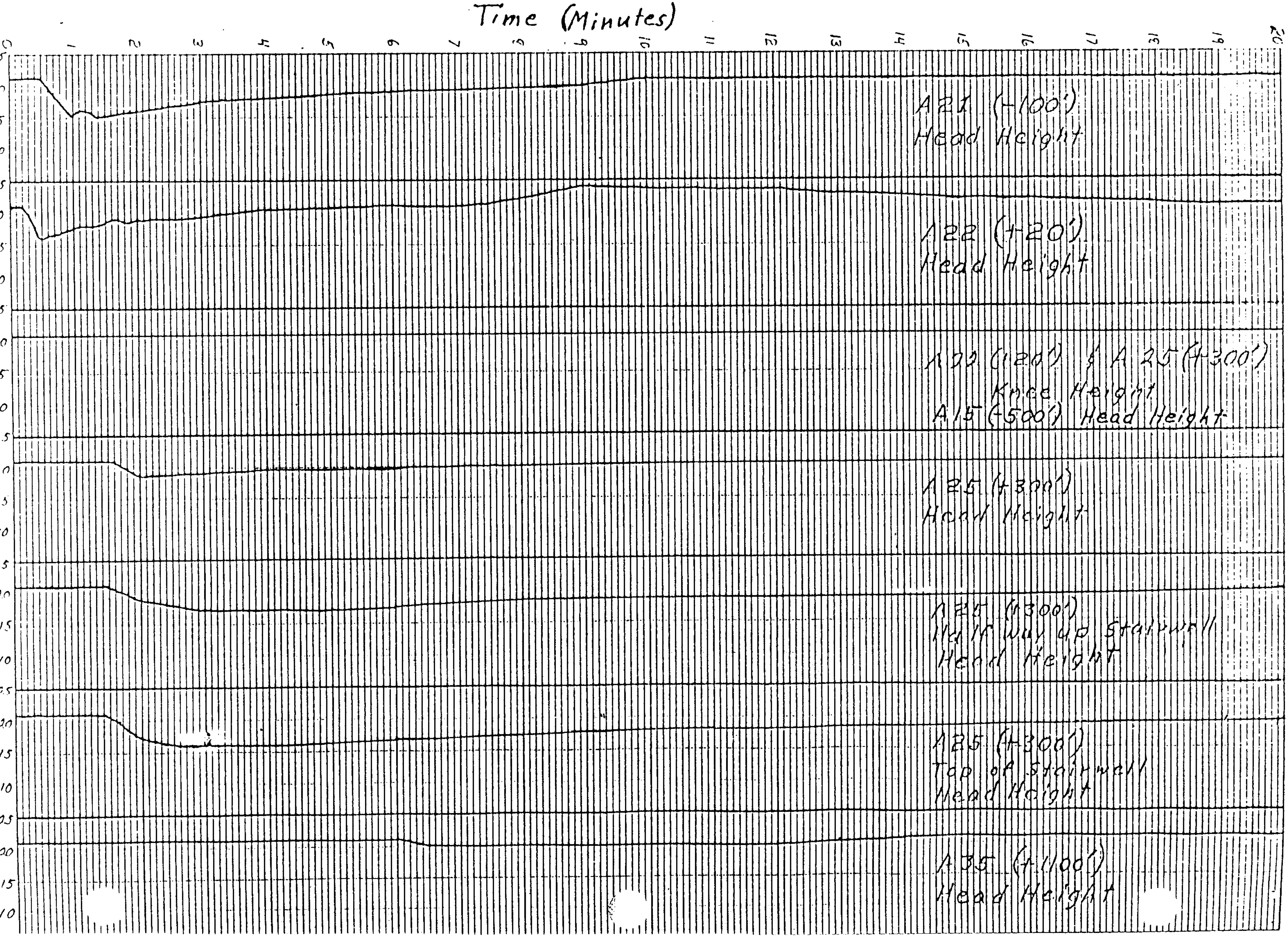

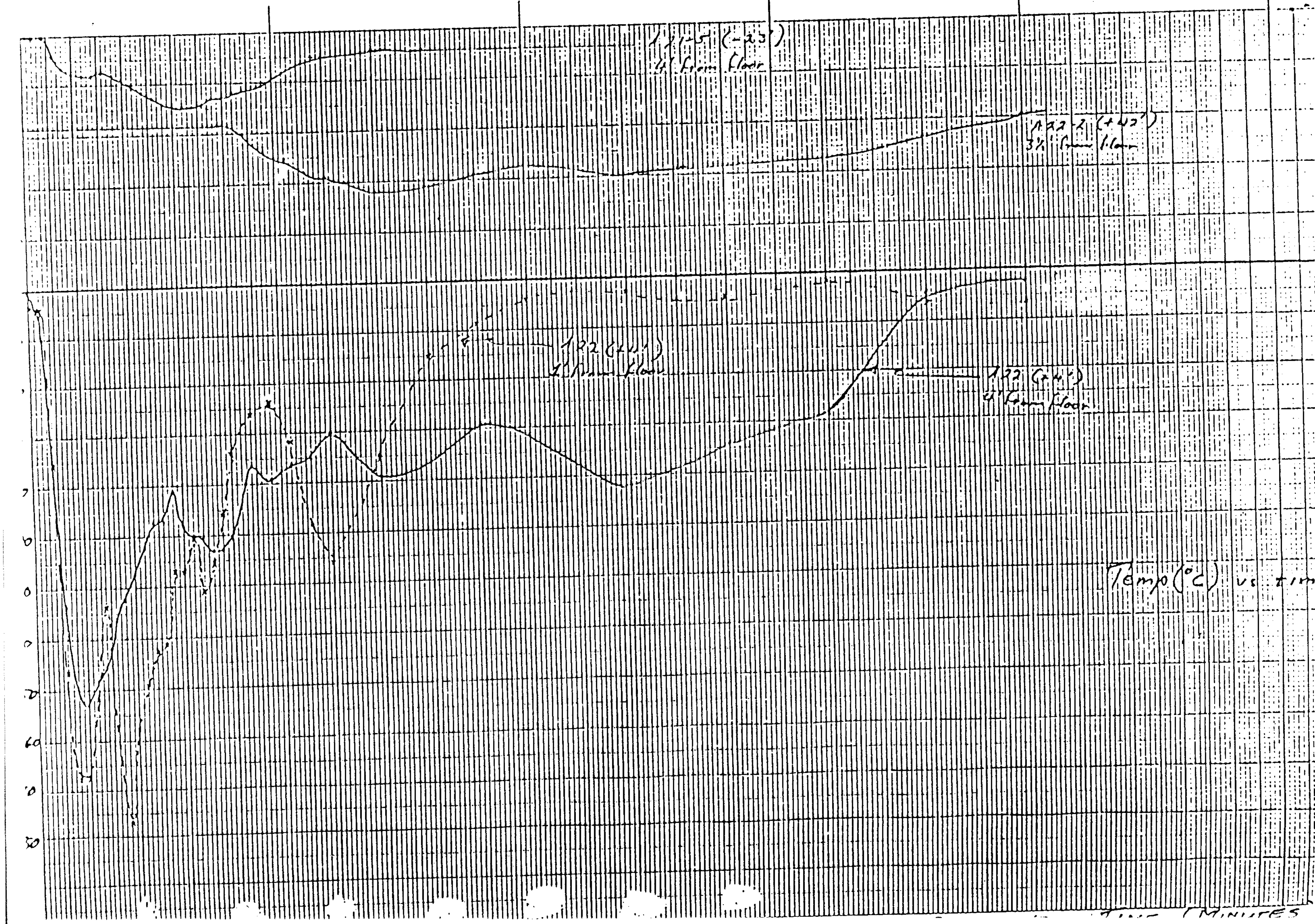

1/1-5 (-23')
4' from floor
A22-2 (+42')
3½' from floor
1/22 (+41')
2' from floor
1/22 (+41')
4' from floor
Temp (°C) vs tim
TIME (MINUTES

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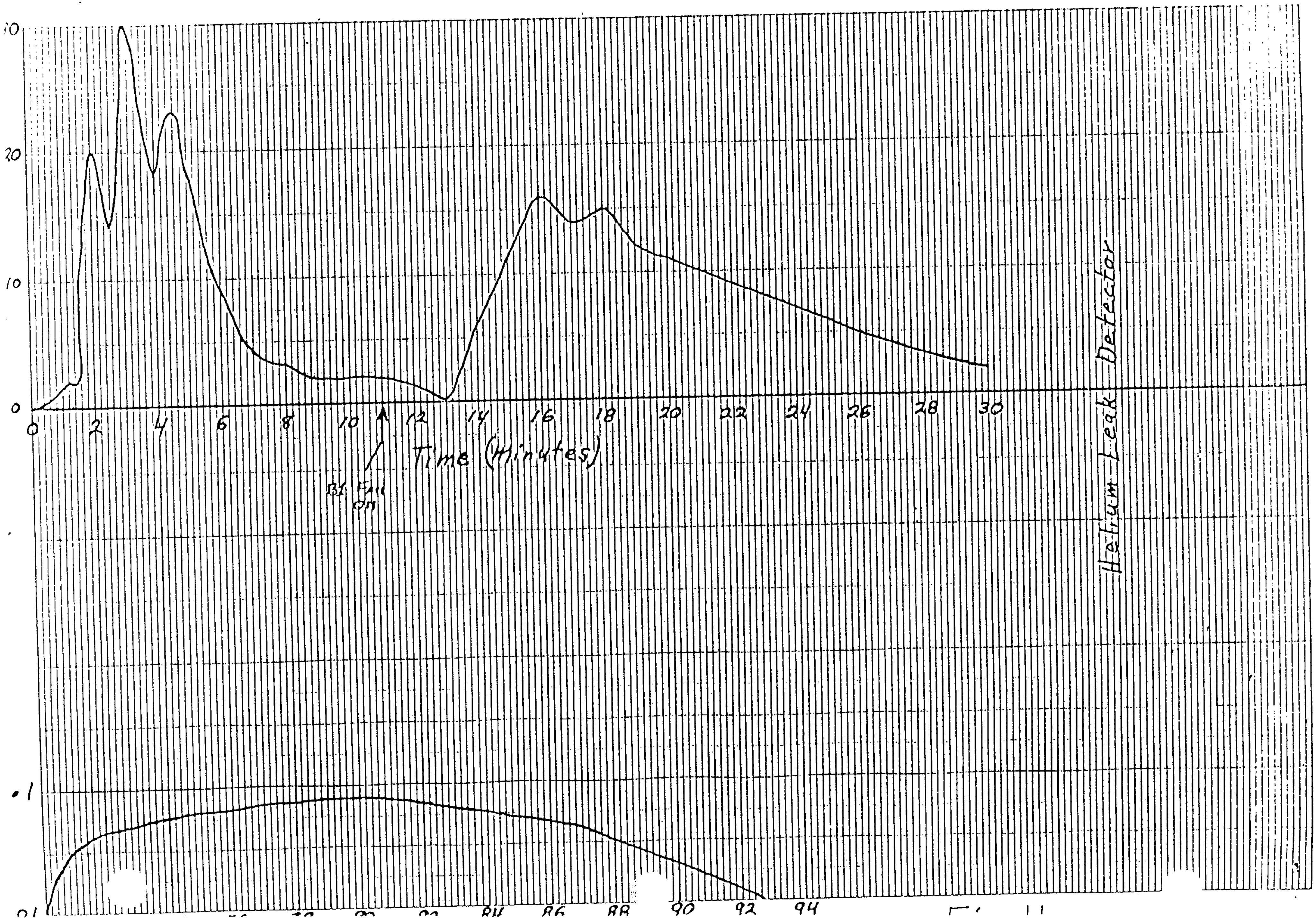


March 8, 1991

Injector Helium Spill Test

Participants: C. H. Rode, W. C. Chronis, M. Keesee, D. Ahlman, D. Brazzale, J. Hansknecht, B. Charlton, H. F. Dylla, G. R. Neil, J. Heefner, H. Robertson.

Purpose

1. Determine ODH hazard in service buildings.
2. Verify civil design for ODH containment.
3. Determine the limits of the "plume" in the tunnel and compare with the Fermilab spill test.

Configuration

1. CHL supplying liquid and shield refrigeration through the North Linac supply transfer line to the FET cryounit and cryomodule.
2. Spill location: 2.2 K supply bayonet of the second cryomodule in the injector had a helium actuated "Kautzky" valve installed; $C_V = 12$ (Fig. 1).
3. Oxygen monitors located per Fig. 2; final North Linac layout plus extra temporary unit in W5 building.
4. Temperature sensors located per Fig. 3; four located at beam elevation 27′ and four located at 100′ elevation.
5. Injector roof louvers shimmed for 1/16 minimum opening.
6. He vent shafts with slot cut in louvers (Fig. 4).
7. Temporary tunnel blockage:
    a. Downstream: 85 MeV shielding wall
    b. Upstream: 46° plastic dust wall
8. Northwest access tunnel has two plastic dust walls.

The Spill

1. The MV11-124 (4.5 K outlet valve) was opened from 0.2 turns to 3.2 turns to reduce the impedance between the refrigerator and the tunnel.
2. The refrigerator controls maintained liquid at 2.8 ATM at its outlet.
3. The "Kautzky" valve was opened; it appears to have reached a flow rate of about 500 g/sec in about 2 sec.
4. After the first minute the flow rate started choking at 100 g/sec; after 12 minutes the "Kautzky" valve was closed. About 700 ℓ (87,500 g, 18,500 cu ft) were spilled. This amounts to about 40% of the injector service building volume.

Results

1. Oxygen Deficiency Measurements

   The primary set of oxygen sensors which were monitored during the spill test are shown in Fig. 2. These sensors were reading oxygen concentrations of 21 ± 1% prior to the spill; this range is typical of the variability noted in the sensor design. The response of these sensors to the spill is shown in Figs. 5 and 6.

   a. Tunnel location sensors I05, in the immediate vicinity of the spill, and L05, located 140 feet into the west arc, fell to 16% and equilibrated in less than one minute after start of spill ($t = 0$). These two sensors triggered the downstairs horn. The He migrated toward W5 SB due to the W5 exhaust fan being on. At head height 10 ft. in front of the "plume", after the initial high flow, the O_2 level was 20.5%.

   b. The Injector Service Building sensors (I02 and I03) decreased by 1–2% with a delayed response of 5–10 minutes after $t = 0$ depending on the path length from the spill to sensor location. It should be noted that these sensors never came to equilibrium during the (12 min) duration of the spill. Since the observed rate of decrease in oxygen concentration was approximately linear, the much larger spills (1600 ℓ) potentially possible with a full cryomodule dump would create significant ODH levels.

   c. Sensor I01 is located at the top of the stairwell; the He reached this location through a 2″ crack at the building roof line.

   d. A significant response was noted in the N. Access Building storage room (L02 $\simeq$ 16%) and stairwell (L03 $\simeq$ 18%) due to the large open conduits from the tunnel to storage room and open door from the storage room to N. Access Building stairwell (Fig. 6).

   e. The sensor in the W5 service building showed no response since the roof louver was fully open with the exhaust fan on.

   f. An insignificant response ($< 0.2\%$) was observed in the N. Access Building (L04) and tunnel areas cordoned off by dust curtains (L01).

2. Tunnel Air Temperature Measurements

   An array of eight thermocouples were positioned in the tunnel in the vicinity of the spill location (Fig. 3). The response of these thermocouples to the He spill is shown in Fig. 7. The observations can be summarized as follows:

   a. The largest temperature drop was recorded by the ceiling sensor (#8) located 10 ft from the spill valve, and showed a temperature decrease to −40°C one minute after $t = 0$.

   b. By two minutes after $t = 0$ all three ceiling sensors (#3, 7, 8) had equilibrated at $T \simeq -16$°C (ceiling sensor #5 was not working).

   c. The air temperature recovered to ambient conditions after termination of the spill with an approximate 30 min time constant.

d. The floor sensor nearest the spill location (#6) showed a transient drop to 0°C during the first minute of the spill; otherwise the steady state response of all the floor sensors (#6, 4, 2, 1) showed no temperature drop (i.e., $T = 20°C$).

<u>Conclusions</u>

1. The North Linac tunnel with no cryomodules could be downgraded to ODH "0".
2. The ODH rating of all other areas is correct.
3. Needed civil modification:
   a. Seal roof to injector stairwell joint.
   b. In tunnel, plug penetrations to access building storage room.
4. The choking of the spill was caused by 2 phase flow in the MV11-124 valve, which was only open 3.2 turns.
5. The cryomodule rupture disk can provide an order of magnitude higher flow and more than twice the spilled quantity of liquid helium. The primary impact will be to produce local areas of $< 15\%$ oxygen, both in the tunnel and in the relay racks; the global effects in the tunnel and service building will not change.
6. The difference between the Fermilab and CEBAF spills are caused by: 1) factor 4 larger tunnel, 2) relief position and direction, and 3) penetrations in roof of tunnel. They resulted in safety differences:
   a. Temperature freezing zone was much smaller; we measured −40°C vs. −150°C at Fermi.
   b. The ceiling cloud was much smaller.
7. As part of the N. Linac test, the spill should be repeated, but with a flow rate of ~1000 g/sec.
8. Warming of the gas in the penetrations results in little visible indication of problem in service buildings. Automatic turn-on of service building vent fans in case of ODH problem should be reviewed.
9. ODH alarms in service buildings should trip on problems in tunnel below.

[spd.rode]spilltest.tex, 6/30/92

IGURE 1
'PILL LOCATION

CEBAF

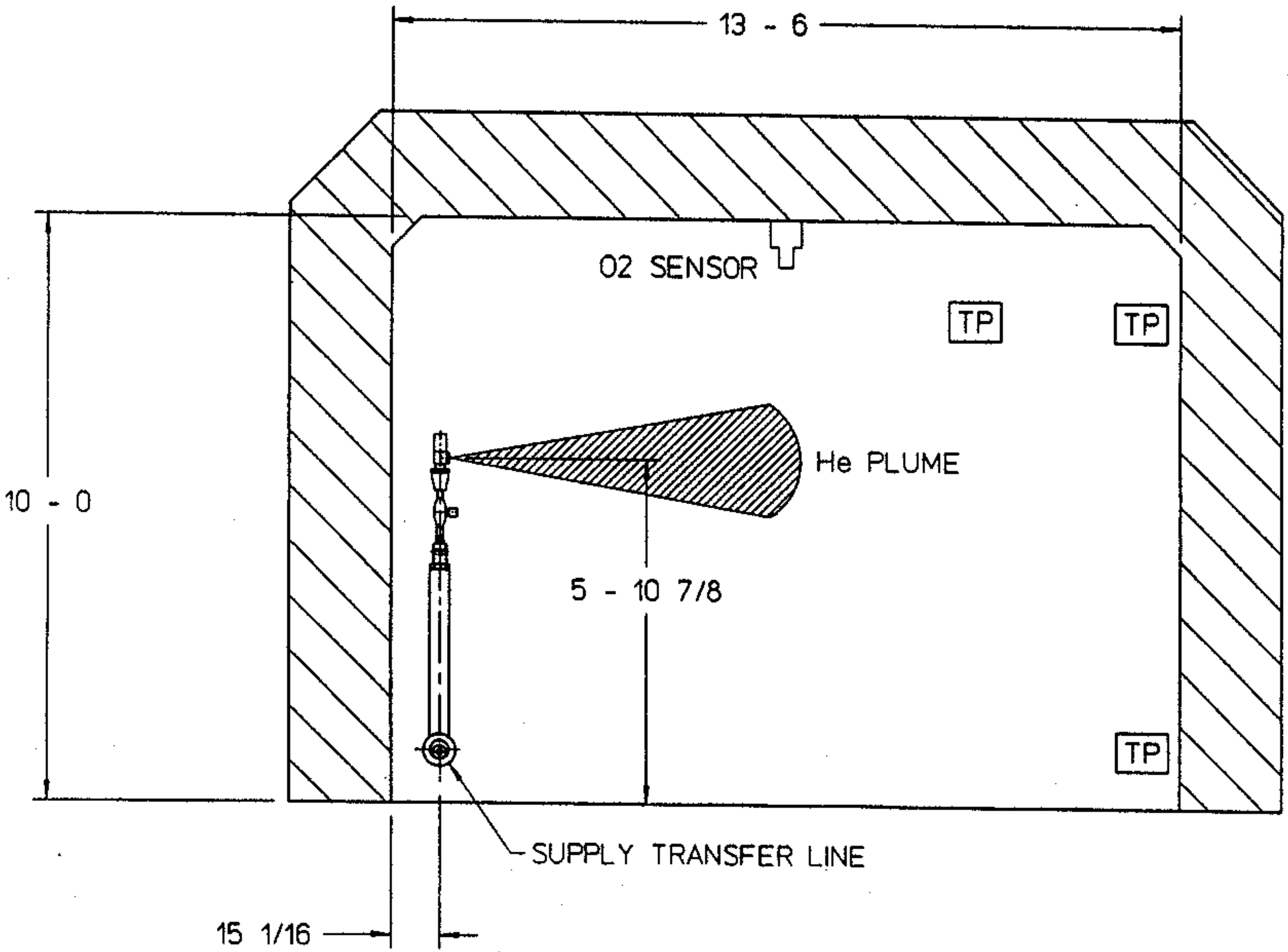
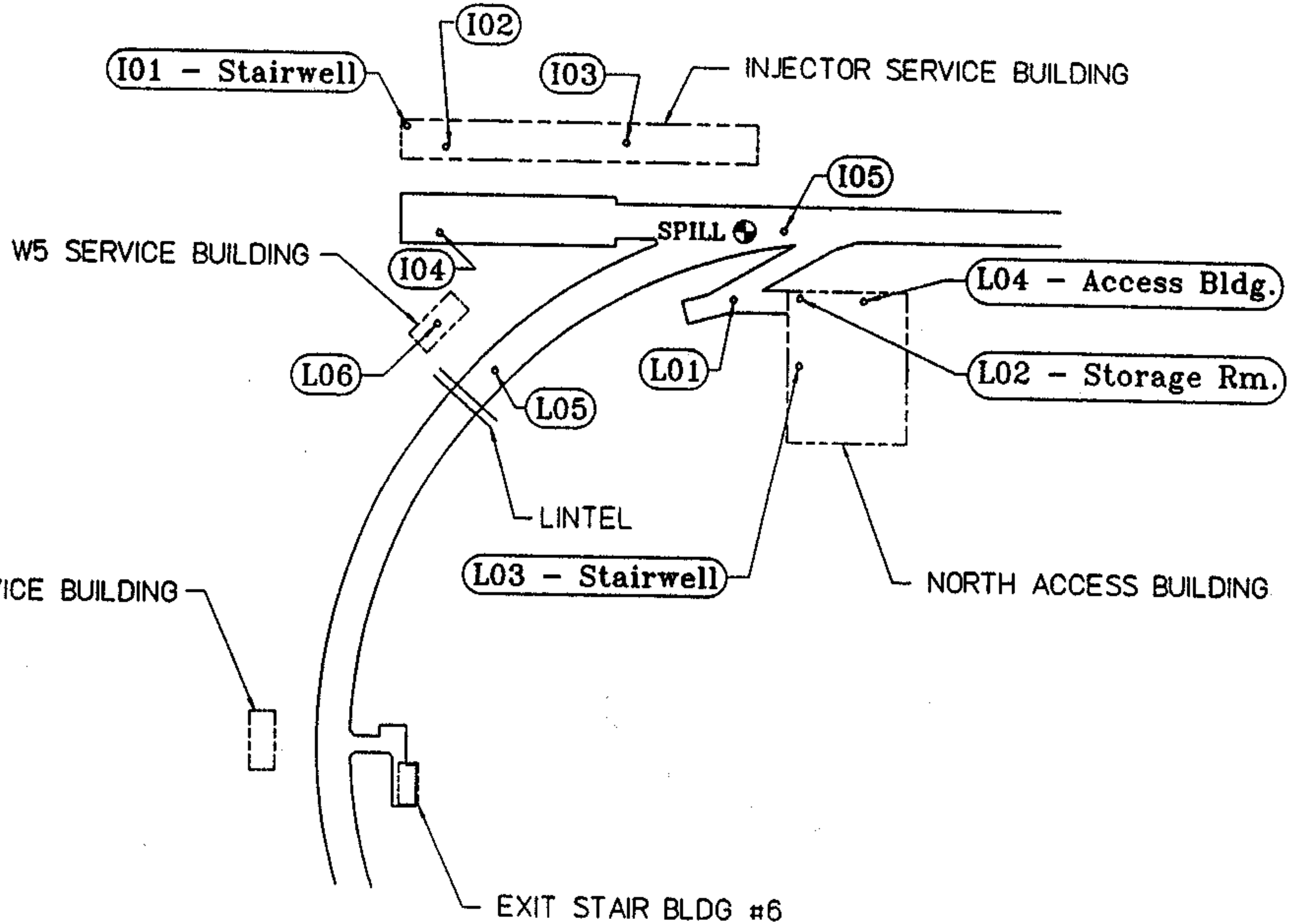


FIGURE 2
O_2 SENSOR LOCATIONS

CEBAF



HR_MISC/lo2_sens_loc

FIGURE 3
TEMPERATURE SENSOR LOCATIONS

CEBAF

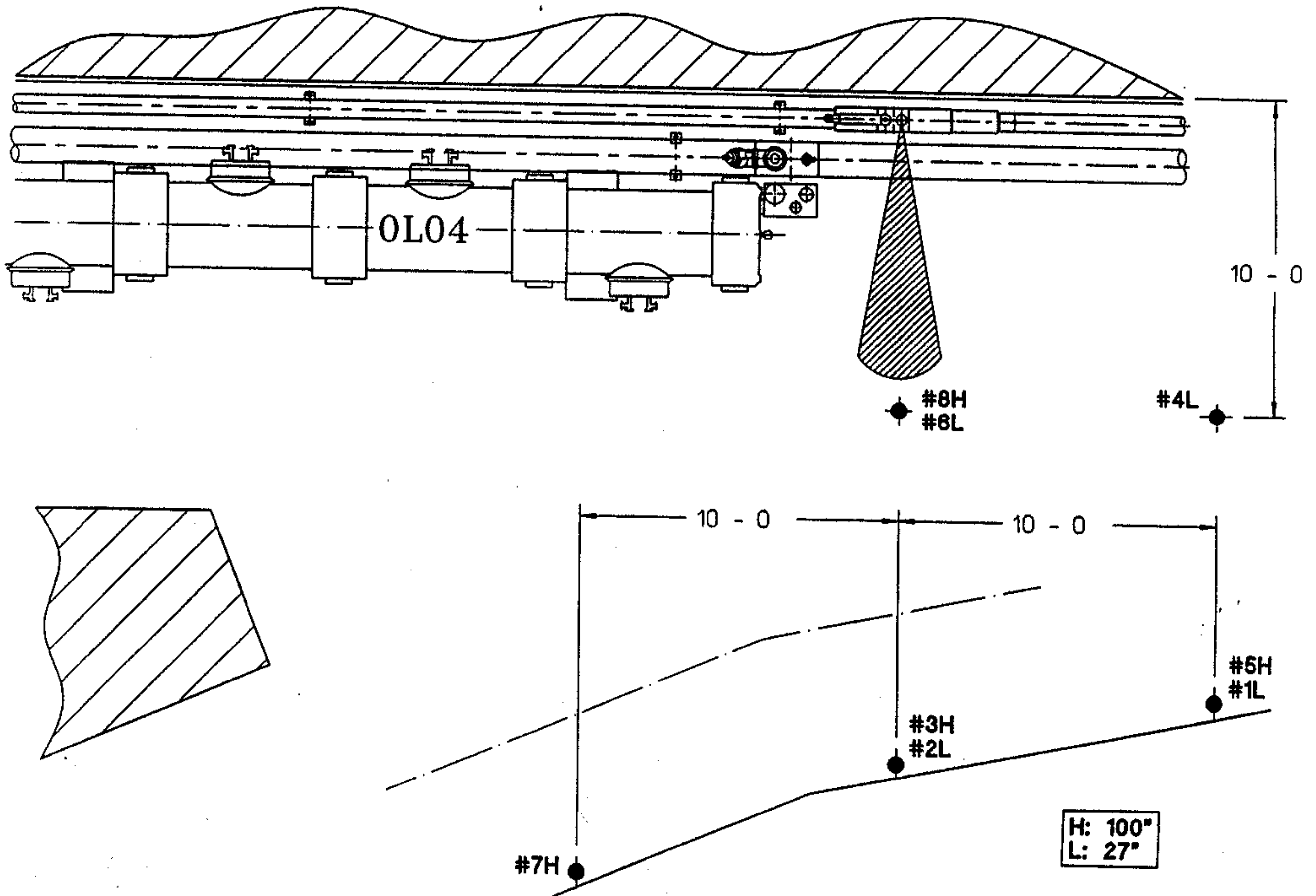
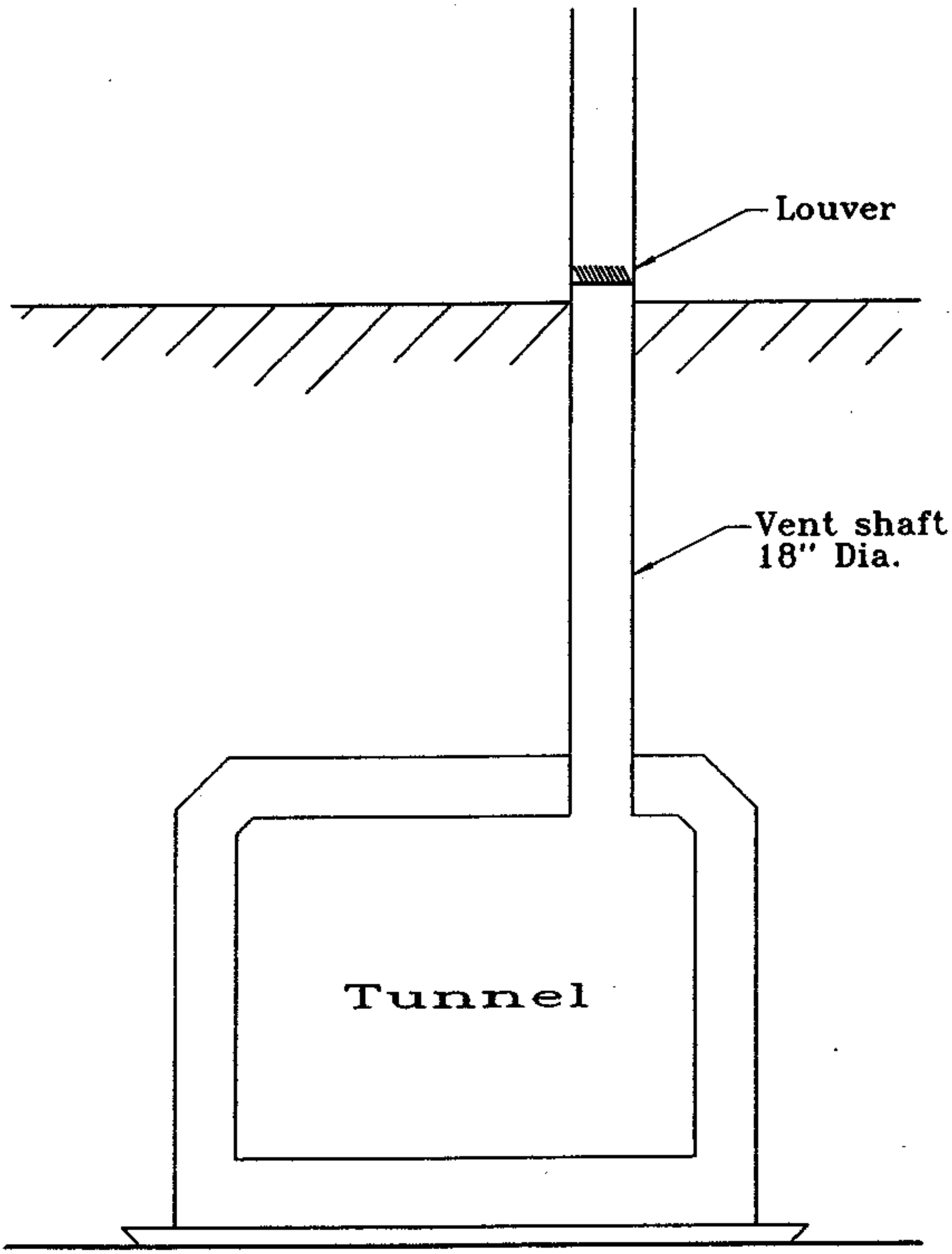


FIGURE 4
He VENT SHAFT

CEBAF



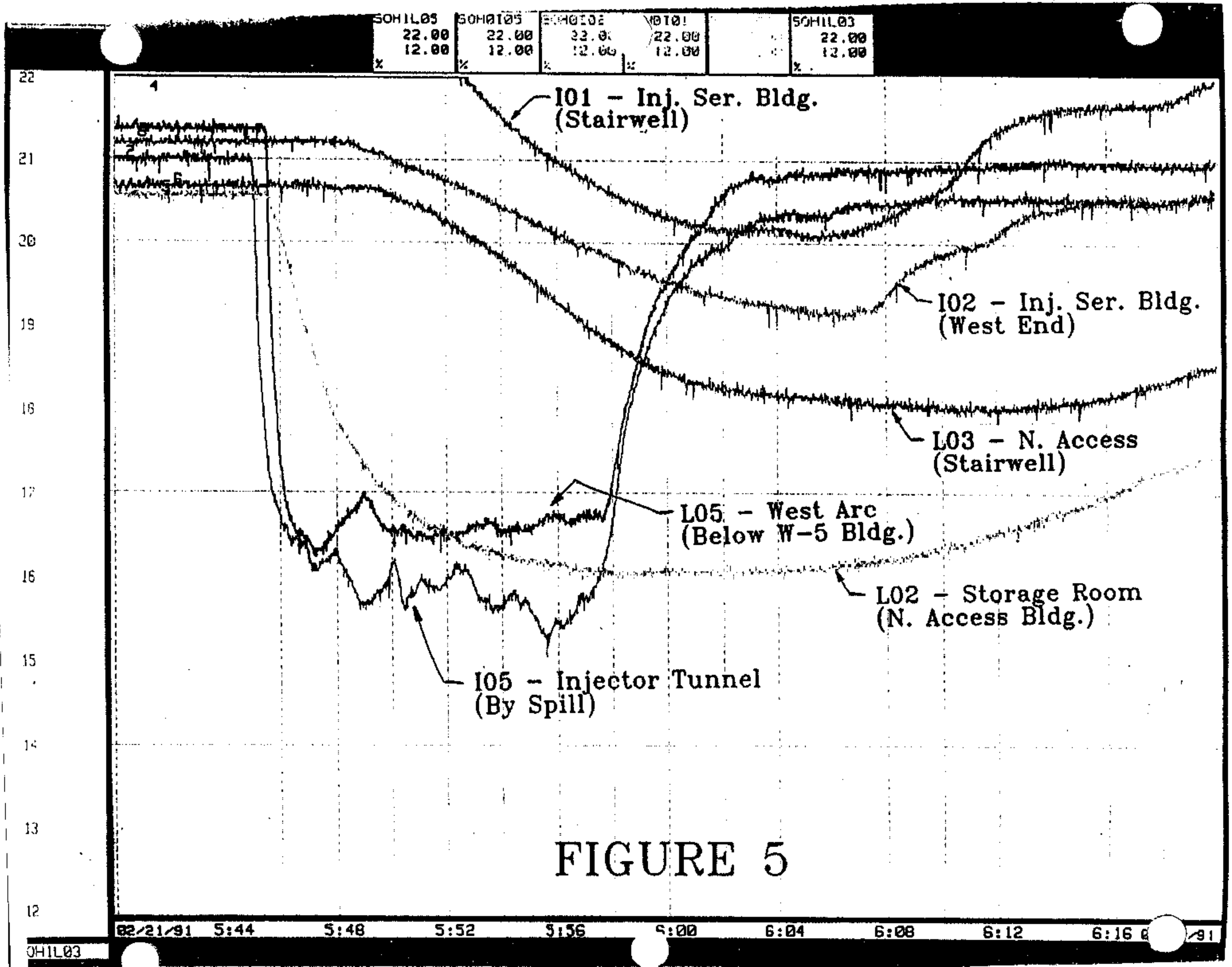

SOHIL05 22.00 12.00 %
SOH0I05 22.00 12.00 %
22.00 12.00 %
22.00 12.00 %
SOHIL03 22.00 12.00 %
22
21
20
19
18
17
16
15
14
13
12
I01 - Inj. Ser. Bldg. (Stairwell)
I02 - Inj. Ser. Bldg. (West End)
L03 - N. Access (Stairwell)
L05 - West Arc (Below W-5 Bldg.)
L02 - Storage Room (N. Access Bldg.)
I05 - Injector Tunnel (By Spill)
02/21/91 5:44
5:48
5:52
5:56
6:00
6:04
6:08
6:12
6:16
0HIL03

FIGURE 5

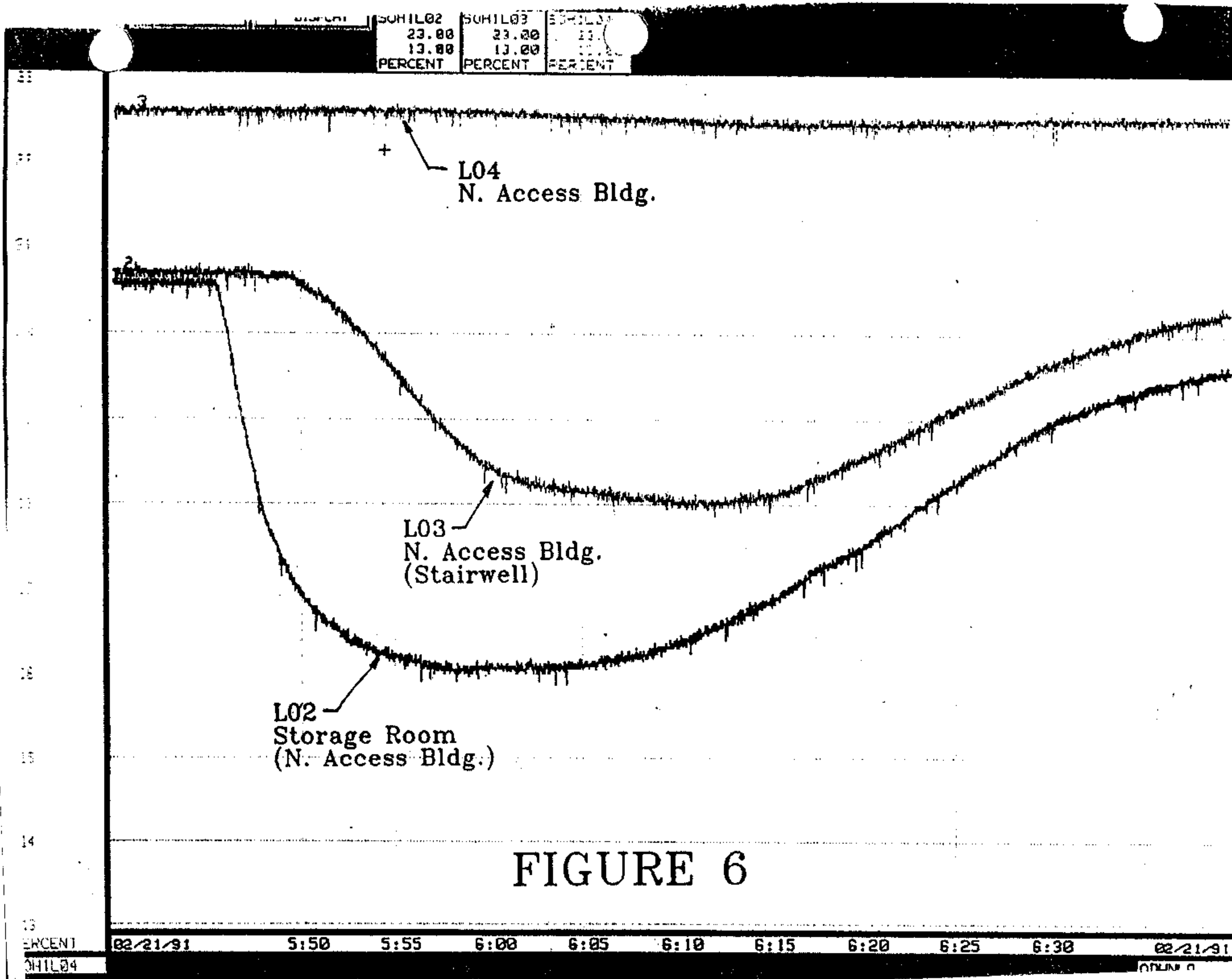

SOHIL02
23.00
13.00
PERCENT
SOHIL03
23.00
13.00
PERCENT
PERCENT
L04
N. Access Bldg.
L03
N. Access Bldg.
(Stairwell)
L02
Storage Room
(N. Access Bldg.)
14
02/21/91
5:50
5:55
6:00
6:05
6:10
6:15
6:20
6:25
6:30
02/21/91

FIGURE 6

FIGURE 7
TEMPERATURE RESPONSE

CEBAF